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Research Report

No Blindness for Things That Do Not Change

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ABSTRACT—***It is well known that under normal circumstances, human observers are able to detect a visual change (a luminance transient) in the outside world very easily. This study demonstrated that observers are also easily able to detect a nonchanging element if it is located in a display containing multiple elements that do change. That is, a nonchanging element popped out from a display containing multiple changing elements (luminance transients). The efficient detection of the nonchanging element may be due to temporal grouping created by the dynamic character of the stimulus display.***

It is well known that the visual system is sensitive to events that exhibit sudden change (e.g., Breitmeyer & Ganz, 1976). Abrupt luminance changes have the ability to involuntarily capture attention (Posner, 1980) and trigger an eye movement (Theeuwes, Kramer, Hahn, & Irwin, 1998) toward the external stimulus. It has been argued that it is important for organisms to detect such sudden changes in the environment because they may be caused by events that require immediate identification and action (e.g., Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Yantis & Hillstrom, 1994).

Under normal circumstances, a change in the outside world is accompanied by a luminance transient in the input signal. However, when this transient input signal is masked by, for example, a gap (Simons, 1996) or "mudsplashes" (O'Regan, Rensink, & Clark, 1999), a striking blindness to change can be induced. Under such circumstances, even observers who are instructed to look for changes may take up to 20 to 30 s before noticing them. It has been argued that changes are detected by focused attention (Rensink, 2002), and in the absence of a luminance transient to attract focused attention to the relevant location, *change blindness* may occur.

The current study addressed the question whether the visual system is also sensitive to things that do not change. In other words, are observers able to determine the only object in a scene that does not change even when all other objects change orientation and location, causing many luminance transients? In this current study, observers viewed a preview display for 1,000 ms. Immediately following the preview display, all elements except one changed position and orientation. The task was to detect the only element that did not change. Experiment 1 showed that this element popped out from the display and could be detected very efficiently. Experiment 2 determined whether the effect was due to iconic memory persistence by introducing a gap (blank display) of 100 or 500 ms between the preview display and the search display. Experiment 3 compared the efficiency of search for a nonchanging element (all elements changed except one) versus search for a single changing element (one element changed while the rest remained the same) for different gap intervals.

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GENERAL METHOD

Observers viewed 4, 8, or 12 horizontal and vertical 0.6° line segments (half vertical, half horizontal). After a 1,000-ms preview, all except one were replaced by new line segments (tilted 22.5° to either side of the horizontal or vertical plane) positioned at new locations within the search display. Observers searched among the second set of elements for a vertical or horizontal line segment, the orientation determining the appropriate response key (press the "/" key for a vertical line segment and the "z" key for a horizontal line segment). In the control condition, each element in the search display changed location and orientation after the preview; all these changed elements except one were slightly tilted, and the one horizontal or vertical line segment constituted the target.

In the experimental condition, observers were told that the nonchanging line segment was the line segment they were looking for. In the control condition, observers were informed that all line segments were new. The centers of the line segments were positioned on an imaginary 5×6 grid. Line segments were presented randomly at any position in the 5×6 matrix ($9.5° \times 13.1°$). Figure 1 give examples of the displays.

Experiment 1

In Experiment 1, there were 5 observers (the author and 4 naive observers). Observers received 720 trials, 360 in the control (all change) condition and 360 in the experimental (no-change target) condition. Each preview set size (4, 8, or 12) was orthogonally varied with each search display size (4, 8, and 12). There was no interstimulus interval (ISI) between the preview and search display. Note that all elements of the preview display except one (the target) changed position and orientation. Target line segments were presented

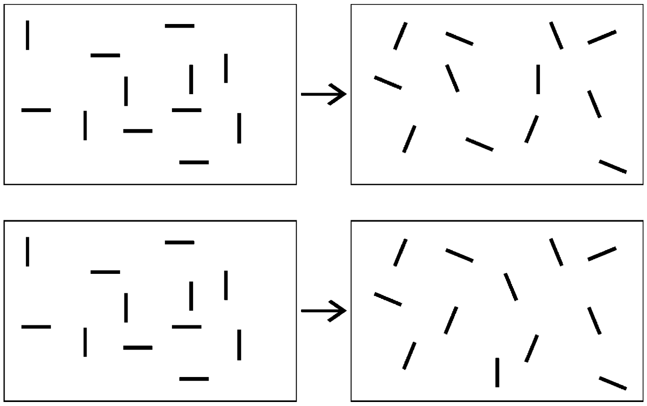

Fig. 1. Sample preview (left) and search (right) displays from the experimental (top) and control (bottom) conditions in Experiment 1. In the experimental condition, one element in the preview display (the third vertical line segment from the right in the top left display) remained unchanged in the search display; all other elements changed position and orientation. In the control condition, all elements changed position and orientation. Participants searched for a vertical or horizontal line segment. In the experimental condition, this segment was the element that did not change from the preview to the search display.

in black on a white screen (24.7 cd/m^2). The luminance of the black line segments varied randomly between 0.6 and 2.1 cd/m^2.[1]

Experiment 2

In Experiment 2, the number of elements in the preview display was always 8; the number of elements in the search display was again 4, 8, or 12. There was an ISI (white screen) of 0, 100, or 500 ms between the preview and search display; ISI was varied within blocks. Participants received 180 experimental trials, and the control condition was not included. The luminance of the black line segments varied between 0.8 and 3.5 cd/m^2. In this experiment, there were 4 observers (the author and 3 naive observers).

Experiment 3

In Experiment 3, observers searched for a constant target among changing nontargets (no-change-target condition) or for a changing target among constant nontargets (change-target condition). The preview display consisted of 4, 8, or 12 elements. There were three possible intervals between the preview display and the search display. After a variable ISI of 0, 120, or 500 ms in the no-change-target condition, all elements except the target element changed orientation (from horizontal in the preview display to 22.5° tilted toward the vertical plane or from vertical in the preview display to 22.5° tilted toward the horizontal plane). The target element was the only element that remained unchanged (it remained vertical or horizontal, the orientation determining the appropriate response key). Note that unlike in Experiments 1 and 2, in Experiment 3 nontargets underwent an orientation change only. In the change-target condition, there were 4, 8, or 12 tilted line segments (22.5° tilted toward either the horizontal or the vertical plane). After 0, 120, or 500 ms, one of these tilted lines changed into a horizontal or vertical line constituting the target element. In total, participants received 720 trials, 360 in the no-change-target condition and 360 in the change-target condition. In Experiment 3, there were 4 observers (the author and 3 naive observers).

[1]I randomly varied the luminance of the line segments in the search display and used a white background for the display to ensure that luminance adaptation, which most strongly applied to the nonchanging element, was not the cause of the pop-out detection. Lucassen and I have shown that adaptation may result in pop-out detection (Theeuwes & Lucassen, 1993).

RESULTS

Experiment 1

The slowest 1% of response times were removed from the analysis. Figure 2 presents, for each observer, the response times as a function of the number of elements in the search display for the experimental and control conditions. As is clear from this figure, when observers searched for the element that did not change, response time was hardly affected by the number of elements in the display.

Table 1 presents the slopes for the experimental and control conditions. Search for the nonchanging element was very efficient, rendering search times in the range considered to reflect preattentive parallel search (e.g., Treisman & Sato, 1990). Observers reported that the nonchanging element popped out from the display, an experience that was confirmed by the data. In the control condition, in which the target element was also a new element in the display, search was inefficient, reflecting typical serial search (e.g., Wolfe, 1994).

The number of elements in the preview display influenced search as well. As shown in Table 2, search times for the nonchanging element increased with the number of elements in the display. Note, however, that this effect was relatively small. Table 3 presents the error rates. There was an overall error rate of 8.9%. Error rates increased with increasing size of the search display.

Experiment 2

Figure 3 presents search slope as a function of ISI for each observer in Experiment 2. As is clear from this graph, at the 0-ms ISI, search slopes were again near zero. At the 100- and 500-ms ISIs, search slopes were large, reflecting serial search among the line segments. Note that search was somewhat more efficient with an ISI of 500 ms than with an ISI of 100 ms. This finding seems to be related to the increase in performance found with increasing intervals in perceptual integration tasks (Brockmole, Irwin, & Wang, 2002). In these tasks, observers have to integrate information from two temporally distinct visual representations (see, e.g., Di Lollo, 1980). Brockmole et al. argued that during longer intervals, observers are able to generate a useful memory representation of the first array, allowing near-optimal visual integration.

Experiment 3

Figure 4 presents search slope as a function of ISI for each observer in Experiment 3. At the 0-ms ISI, search in the change-target condition was quite efficient. Detection of the no-change target was also efficient at this ISI (between 9 and 34 ms/item), but somewhat less efficient than in the experimental conditions of Experiments 1 and 2, in which the nontargets not only changed orientation but also changed location. At the 120-ms ISI, there was a very large difference between the no-change-target and change-target conditions. Change-target detection remained fairly efficient, with search slopes up to about 20 ms/item,

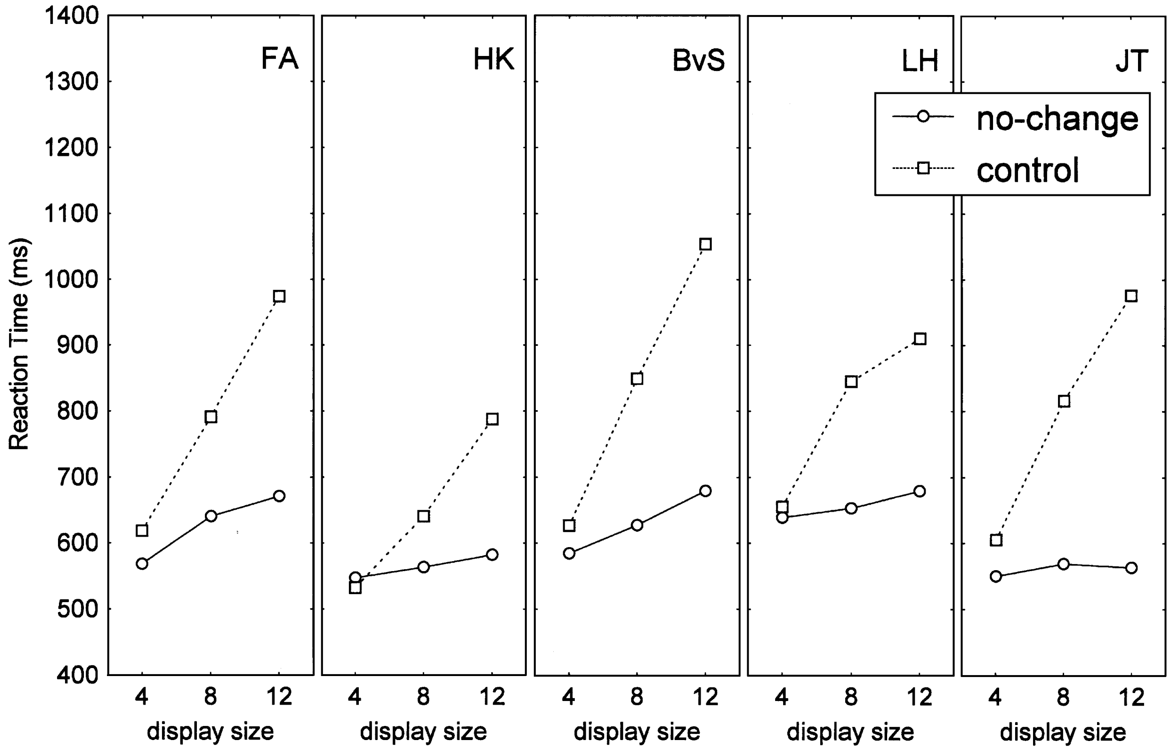

Fig. 2. Results from Experiment 1: Reaction time as a function of display size in the experimental and control conditions for each individual observer.

whereas no-change-target detection became very inefficient (search slopes up to 52 ms/item). Basically the same pattern of results was found with an ISI of 500 ms.

DISCUSSION

In conditions in which there was no interval between the preview and search displays, the element that did not change popped out from the search display (Experiment 1). When an interval between the displays was introduced, search for a nonchanging element became very inefficient (Experiments 2 and 3). At the same time, even with an interval, search for a single changing element remained fairly efficient (Experiment 3). The findings of Experiment 3 are in line with those reported by Rensink (1999, 2000). Rensink (1999) used a flicker paradigm in which alternating versions of a search scene were displayed, separated by a blank interval for 120 ms. With this paradigm and with different types of stimuli, search slopes for detecting a changing element were about 100 ms/item, whereas search slopes for detecting a nonchanging element were about 300 to 400 ms/item. Even though Rensink's paradigm and stimuli were quite different from those in the present study (which makes a direct comparison between the search slopes impossible), the current findings are qualitatively very similar to those obtained by Rensink. With a 120-ms blank interval, as in Rensink's experiments, search for a nonchanging element was about 2 to 3 times more inefficient than search for a changing element. These findings can be explained by assuming that the capacity for presence of change is much higher than the capacity for absence of change (Rensink, 1999); a similar explanation has been used to interpret the search asymmetry for simple features (Treisman & Gormican, 1988; see also Royden, Wolfe, & Klempen, 2001, for search asymmetries with dynamic, moving stimuli).

TABLE 1

Effect of the Number of Elements in the Search Display (Search Slopes in Ms/Item), Experiment 1

Condition	Observer F.A.	H.K.	B.v.S.	L.H.	J.T.
Search for the nonchanging element	12.8	4.3	11.8	5.0	1.6
Search for a new (changed) element	44.5	32.0	53.5	31.8	46.3

TABLE 2

Effect of the Number of Elements in the Preview Display (in Ms/Item), Experiment 1

Condition	Observer F.A.	H.K.	B.v.S.	L.H.	J.T.
Search for the nonchanging element	9.6	6.3	1.8	1.6	2.1
Search for a new (changed) element	9.1	0.0	– 9.0	– 4.8	– 2.7

TABLE 3
Error Percentage, Experiment 1

	Size of search display		
Observer and condition	4	8	12
F.A.			
Search for the nonchanging element	12.5	15.0	11.6
Search for a new (changed) element	11.0	7.5	7.5
H.K.			
Search for the nonchanging element	6.6	10.8	13.3
Search for a new (changed) element	4.1	5.8	11.6
B.v.S.			
Search for the nonchanging element	6.6	10.0	13.3
Search for a new (changed) element	9.1	6.7	9.1
L.H.			
Search for the nonchanging element	2.5	6.7	10.8
Search for a new (changed) element	2.5	5.8	10.8
J.T.			
Search for the nonchanging element	5.0	8.3	14.1
Search for a new (changed) element	7.5	10.8	11.6

Given these earlier findings regarding the inefficient detection of a nonchanging element, the current results are quite striking. Even though there were numerous transient luminance changes all over the display, observers were able to detect the only nonchanging element very efficiently. The element that did not change popped out from the display. Nakayama and Mackeben (1989) reported a related effect. In their "decoy" experiment, they showed that a nonchanging element could act as a salient cue for visual attention. How can these results be understood given numerous studies showing that luminance changes attract attention exogenously and given change-blindness studies showing that observers fail to detect large changes in a display when they are masked by multiple onsets (e.g., mudsplashes)?

The efficient detection of the nonchanging element may well be due to temporal grouping created by the dynamic character of the stimulus display. The visual system can segregate a visual scene into separate regions based on temporal cues (e.g., Blake & Yang, 1997; Fahle, 1993; Theeuwes, Kramer, & Atchley, 1998; Watson & Humphreys, 1997). The current findings suggest that the temporal structure allows an efficient segregation of stationary (nonchanging) and dynamic (changing) elements. Obviously, the visual system can have immediate access to the nonchanging element despite the attention-capturing properties of the transient nontarget elements. Recently, a similar notion referred to as segregation by temporal asynchrony was suggested to account for preview benefit in visual marking studies (see, e.g., Jiang, Chun, & Marks, 2002).

Nonchange detection seemed to be slightly more efficient when all elements of the preview display changed in both orientation and location (as in Experiments 1 and 2) than when the elements changed in orientation only (as in Experiment 3). This observation may be related to the temporal-grouping explanation. The grouping signal may be stronger when all elements change in both orientation and location than when only orientation changes.

There is another way to explain the current results. If one assumes that the preview display remains in some kind of visual buffer, a

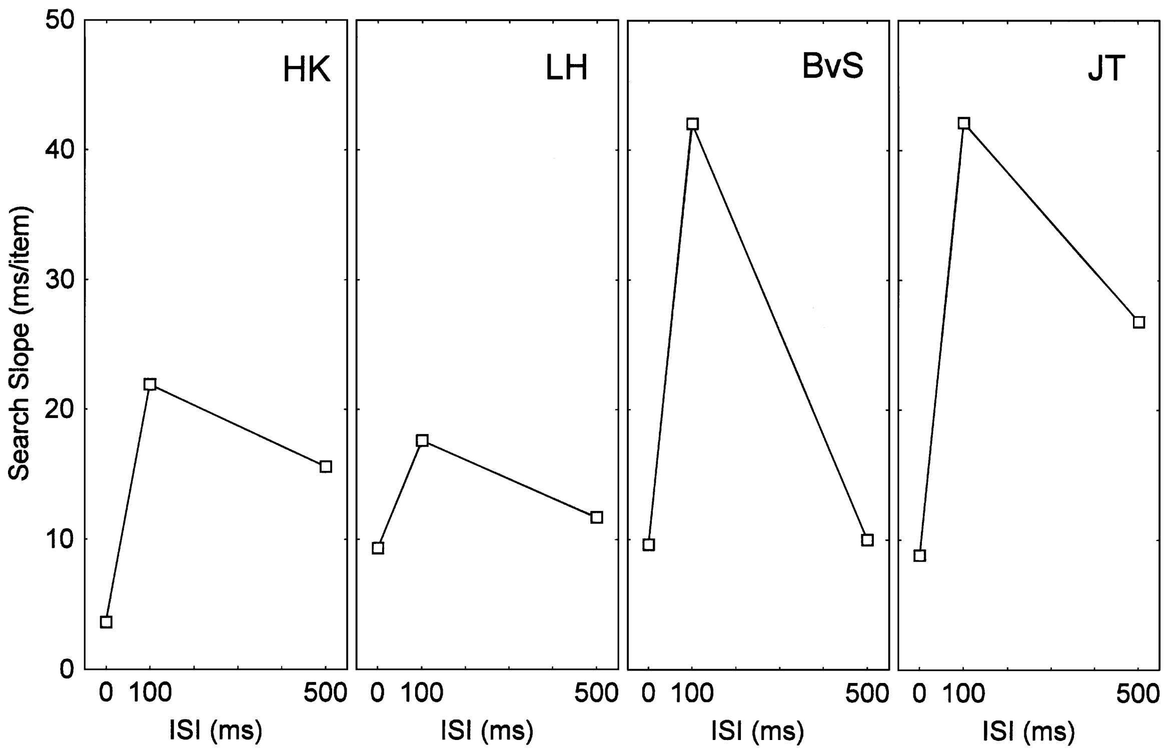

Fig. 3. Results from Experiment 2: Search slope as a function of interstimulus interval (ISI) for each observer. Observers searched for a nonchanging element among changing elements.

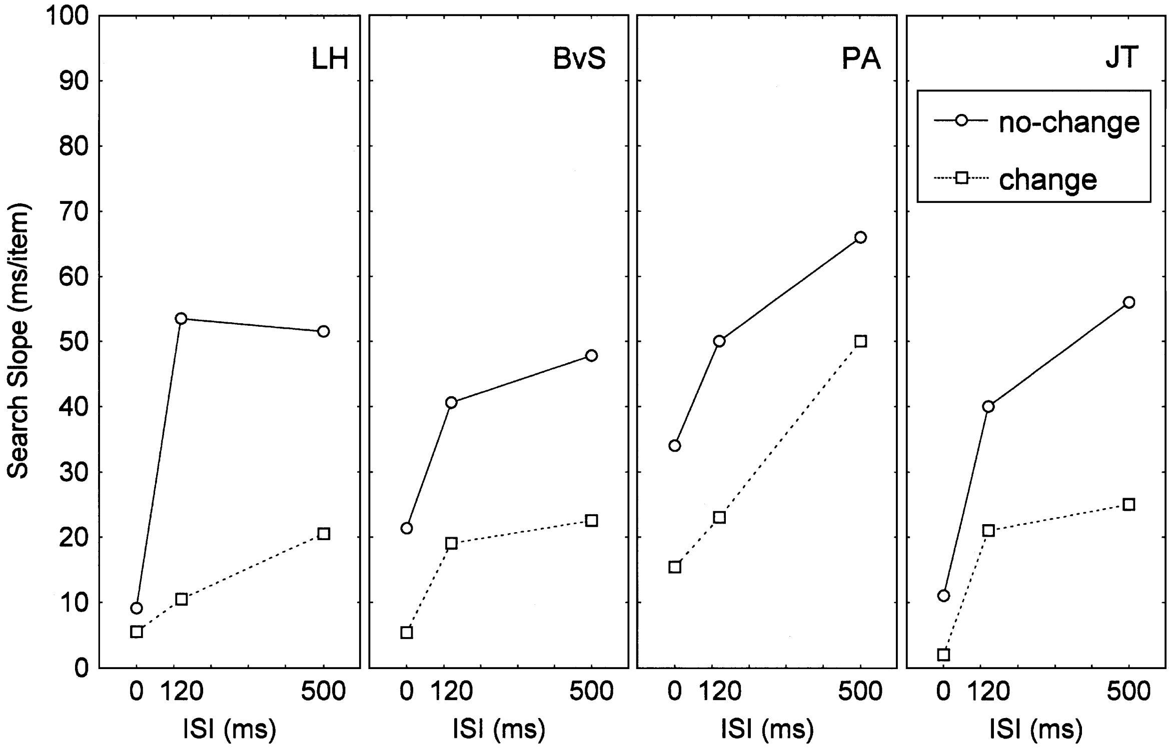

Fig. 4. Results from Experiment 3: Search slope as a function of interstimulus interval (ISI) for each observer. Observers searched either for a single element that changed or for a nonchanging element among changing elements.

preattentive, parallel comparison between the successive displays is possible. Indeed, at any moment in time, there exists a detailed retinotopic representation of the incoming light. Partial-report studies have shown that this iconic memory persists for only about 300 ms (Sperling, 1960). However, Experiments 2 and 3, in which there was a gap (blank) between the preview and search display, indicated a complete breakdown of the pop-out in the no-change condition. Given that the gaps employed (100 ms and 120 ms) are clearly within the limits of informational persistence of iconic memory, it is unlikely that the current effect is related to persistence of iconic memory.

It is also unlikely that detection of the nonchanging element was based on a visual short-term memory comparison between preview and search displays. Visual working memory has a limited capacity with a maximum of 4 elements (Luck & Vogel, 1997), and the fact that the number of elements in the preview display (up to 12 elements) hardly affected search confirms the idea that memory has nothing to do with the current effect.

The current results demonstrate that we are not blind for things that do not change. It has long been known that we are able to detect a single transient signal; the current findings suggest that we are also able to detect a single no-transient signal.

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